FIRE HAZARD ASSESSMENT IN SUPPORTING FIRE PROTECTION SYSTEM DESIGN OF A CHEMICAL PROCESS FACILITY

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ABSTRACT

Because fires in a chemical process facility are a major concern when evaluating public health hazards, a fire hazard assessment plays an important role in supporting a cost-effective fire protection design, while meeting the stringent safety requirements imposed by federal and local government regulations.

The components of a fire hazard assessment include conceptual facility design, operations familiarization, identification of fire potential, hazard magnitude assessment (loss of life and property damage), design criteria, special requirements, design recommendations, fire analyst/facility designer interaction, document analyses, and design resolutions. At DOD facilities, the fire protection system design assessment (as required in MIL-HDBK-1008B, Ref. 1) is used as a final check to confirm that the fire protection design meets the design criteria and assesses the design safety factor.

A fire hazard assessment in postulated scenarios identifies the expected level of harm and property loss resulting from the exposure to a fire and its toxic effluent. The results of the assessment serve as guidelines for designers to provide adequate fire protection systems in order to minimize the fire occurrence, contain the release of hazardous materials, ensure process control and safety feature reliability, achieve the acceptable level of life safety, and reduce property damages to an acceptable level. The keys to the most cost-effective design are to conduct an assessment early in the design and keep the assessment concurrent with the design development.

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1.0 INTRODUCTION

The possibility of uncontrolled fire accidents in the chemical industries increases the concern over the safety of the chemical process facilities. The growing fire risk compels us to reevaluate and improve our current methods and identify new approaches in dealing with fires in these facilities. The primary goal of a fire hazard assessment is to eliminate catastrophic fire incidents through the identification of potential ignition sources. A fire hazard assessment includes the identification, assessment, and recommendations of controls that will prevent injuries and damage.

The fire hazard assessment in chemical facilities is most effectively initiated in the design stage and is carried on into the operation of the facilities. A thorough fire hazard assessment can establish intelligent "fire safety criteria" for designing a chemical process facility so that minimal administrative procedures will be required in later plant operation.

The fire hazard assessment depends on a systematic approach in identifying all the critical locations of fire. The level of fire hazard identification depends on the familiarity and expertise of the fire hazard analyst. This assessment is an important step because, although it is almost impossible to exhaust all the fire cases, it is paramount not to miss the critical ones.

The fire hazard assessment evaluates the fire occurrence potential, assesses the magnitude of the hazard, accounts for the life safety features, recommends design requirements, and documents the analysis. The goal is to provide an acceptable degree of fire safety design in order to prevent or reduce the possibility of the loss of life and property damage.

2.0 GENERAL APPROACH

A fire hazard assessment provides the minimum design criteria that a fire protection system must meet in order to satisfy applicable design constraints. A fire hazard assessment performed during the design stage starts with a review of the design document and continues to a selection of the critical locations of fire. After the locations are identified, a fire incident is postulated based on the possible ignition sources and combustible loading within that location; then, based on the fire protection response, different fire scenarios are developed. The consequence of fire hazards on potential hazard types is measured. Potential hazard types can be a combination of public illness, personnel injury, toxic chemical release, and/or property damage. Based on the fire protection design policy, recommendations are given to minimize the fire hazards to an acceptable level. The recommendations are commented on by both the design group and management. The approved recommendations will be implemented in the fire protection design criteria. The fire protection design criteria may require further design capabilities. The feasibility of the proposed design changes is evaluated before the design is implemented. After the design is completed, the fire protection system design is analyzed to confirm that the design meets the fire protection design criteria. Figure 1 outlines the fire hazard assessment in supporting a chemical process design.

A fire hazard assessment will use a fire model to estimate the response time and measure both the extent of damage and the level of the life safety in fire scenarios where the fire hazard magnitude is considered beyond a level that is generally covered by fire codes and standards. A fire model is used to analyze the proposed design and measure the fire protection response needed to maintain an acceptable level of fire risk. The fire hazard assessment is an effective tool to define the fire protection design criteria. The following subsections describe the method of approach in performing a successful fire hazard assessment.

2.1 DESIGN FAMILIARIZATION

Before a fire hazard analysis can be developed, an analyst must become familiar with the design requirements. Relevant information for the fire protection system comes from a design discipline interview and several documentation sources, including design development criteria, technical drawings, and the system control logic diagrams. The design document describes the type of construction, height and area limitation, occupancy classification, and building separation. Depending on the stage of the design development, the design information can range from a conceptual design requirement to the detailed process and instrumentation drawings (P&IDs) and process flow diagrams (PFDs).

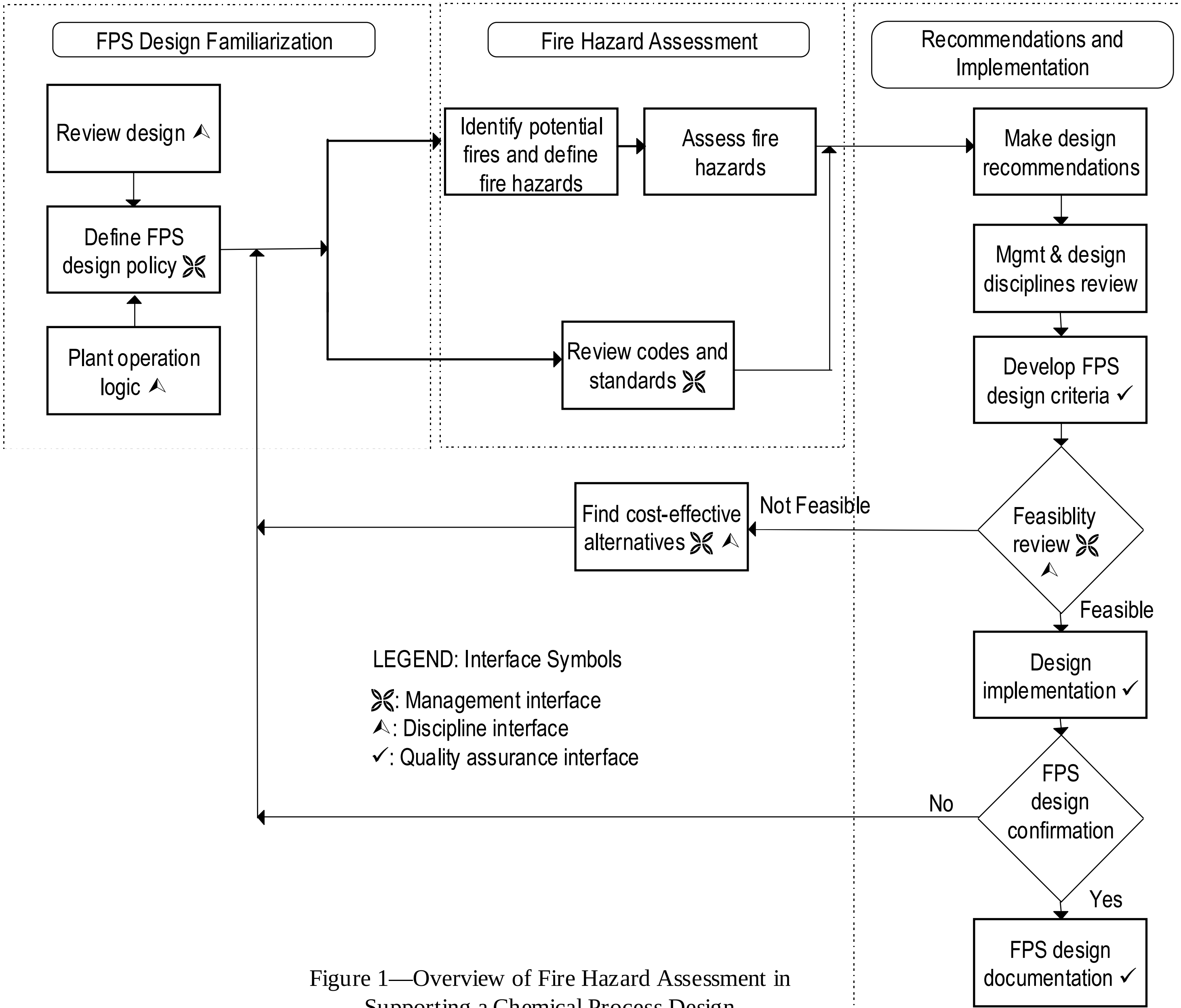

Figure 1—Overview of Fire Hazard Assessment in Supporting a Chemical Process Design

A chemical process design is a multidisciplinary effort that could require familiarity with many technical areas. The chemical processes can range through a wide variety of processes that have unique characteristics. The plant operation logic is developed describing the process sequence, and it breaks down the process into orderly subcomponents by making realistic assumptions and simplifications. Project and process design criteria are reviewed to develop the plant operation symbolic logic diagrams showing the functional relationship of the major equipment.

The scoping document describes the design policy and identifies the requirements for the control of hazards. The fire protection system design policy is usually a measure of the public's acceptance of a risk, combined with management policy concerning financial loss acceptance criteria.

2.2 ASSESSMENT PROCESS

A fire hazard assessment must be started by identifying the applicable fire standards and codes. The following series of governing documents is used to evaluate the adequacy of the fire protection design:

- NFPA 10: Portable Fire Extinguishing System
- NFPA 13: Installation of Sprinkler Systems
- NFPA 15: Water Spray Fixed Systems
- NFPA 17: Dry Chemical Extinguishing Systems
- NFPA 72: National Fire Alarm Code
- NFPA 75: Standard for the Protection of Electronic Computer/Data Processing Equipment
- NFPA 101: Code for Safety to Life from Fire in Buildings and Structures
- NFPA 1221: Installation, Maintenance, and Use of Public Fire Service Communication Systems
- NFPA 2001: Clean Agent Fire Extinguishing Systems
- UBC: Uniform Building Code

A chemical process usually involves flammable chemicals, toxic compounds, and explosive materials. Given these components, the consequence of a fire can be beyond the scope of applicable fire codes and standards. A fire hazard assessment will identify potential fires and types of fire hazards; the consequence of a fire is assessed by measuring the fire protection response to a potential fire condition.

2.2.1 FIRE HAZARD IDENTIFICATION

Fire is a product of fuel being ignited by an ignition source in the presence of oxygen. Therefore, three parameters (fuel, ignition source, and oxygen) are needed for a fire to occur. For most fire scenarios, the presence of oxygen is certain at the initial fire stage. Finding fire hazards requires a systematic approach because of the wide variety of chemical process designs. Most fire hazard identification techniques, originally developed for the nuclear-type facility, can be applied to the chemical industry. Fire hazards can be defined by identification of (1) critical locations and (2) credible fire scenarios.

To identify critical fire locations, an analyst needs to define the fire areas. A fire area is considered as a boundary across which a fire is unlikely to propagate. For example, an area separated by fire walls or a detached structure is classified as a fire area. Each fire area can be divided into fire zones, and each zone is protected by its independent fire protection system. Each zone is further divided into compartments that are separated from each other by nonfire-rated walls (or less than a 1-hr fire wall). Critical compartments within each zone are identified in accordance with the following criteria:

(1) High probability of fire ignition

(2) Fast fire growth

(3) Extreme combustible loading

(4) Vulnerability of safety-related equipment

(5) Potential for injury or loss of life

(6) Significant financial loss

Fire scenarios are selected to include a worst-case scenario. This type of scenario occurs when a fire can cause the most significant damage to the safety-related equipment before any detection and/or suppression is initiated. When safety-related equipment such as control panels or pressure safety valves become disabled, they can adversely impact the safety of operations. Each fire scenario will include the size of fire, fire protection system, sensitive equipment, and fire propagation rate. Based on historical fire data, the worst-case scenarios are developed and evaluated. The historical fire data is considered in estimating ignition sources to initiate a fire. In each fire scenario after a fire is initiated, the fire needs to be detected before the suppression is started.

Fire detectors play a significant role in the success of any fire suppression measure. A poorly selected fire detector results in the failure to respond during the critical fire growth time. Figure 2 is a schematic of a fire scenario with an automatic fire suppression system. Unacceptable fire damage results from either the failure of the fire detection system or an unavailable fire suppression system.

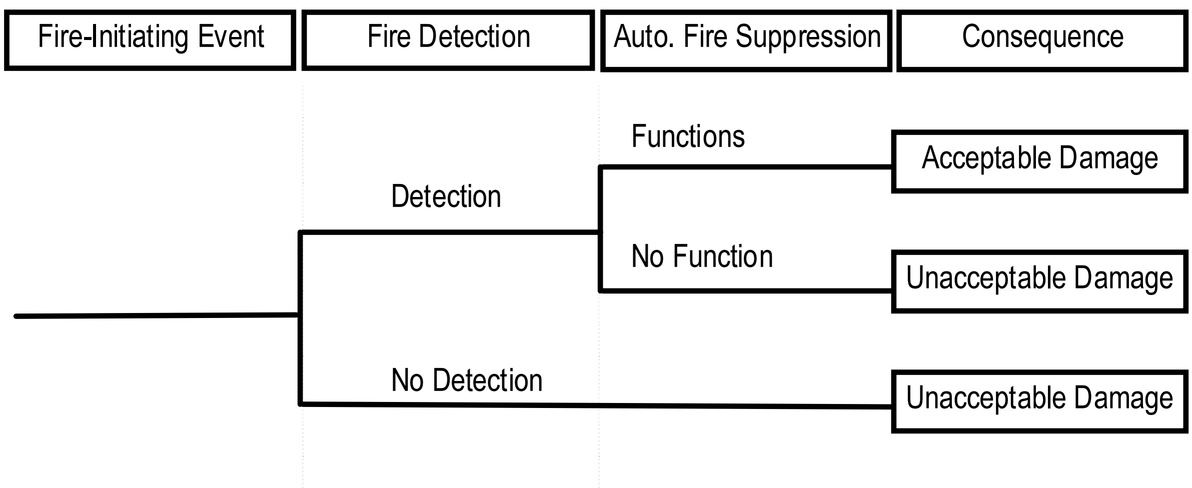

Figure 2—Fire Event Tree for Areas with Automatic Fire Suppression System

Figure 3 is a schematic of a fire scenario with an automatic fire detection system and a manual fire suppression system. Unacceptable fire damage can be resulted by either the failure of the fire detection system or the failure (or delay) of the manual fire suppression system.

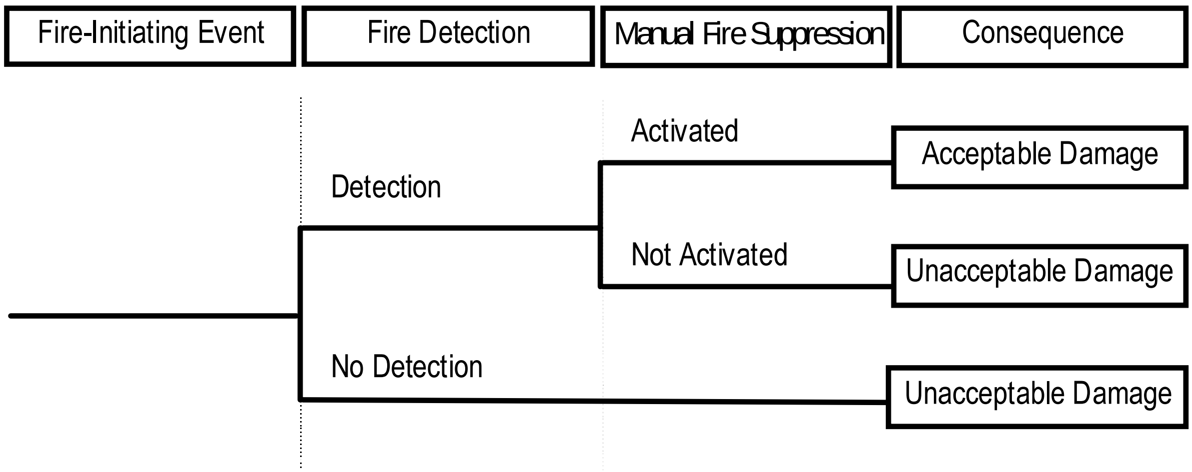

Figure 3—Fire Event Tree for Areas with Manual Fire Suppression System

2.2.2 FIRE HAZARD ASSESSMENT

Two types of fires are postulated: those with acceptable fire damage and those with unacceptable fire damage. The acceptable fire damage is the largest fire loss consequence in a fire location with fire suppression actuated successfully. The unacceptable fire damage is the largest possible fire loss consequence in a fire location, assuming no mitigating fire protection actions. To establish the minimum required fire protection features, each fire scenario will be assessed for each critical fire location. The assessment will consider the effectiveness of the fire barriers in preventing the spread of fire between the fire locations.

From the event trees developed as shown in Figures 2 and 3, the most probable fire scenarios for both the acceptable and the unacceptable fire types will be identified. The fire hazard assessment uses the postulated fire scenarios to determine the extent of property damage or possible loss of life. Assuming that the fire suppression system operates successfully, the extent of the damage will be assessed based on the time needed to actuate the fire detectors for an acceptable fire damage. In the case of unacceptable fire damage, however, the fire suppression system fails to operate, resulting in a fire that will continue until all the combustibles are consumed.

The traditional fire hazard assessment uses the equivalent fire severity by comparing the total heat of combustion of a given fuel package with a known constant. The methodology for estimating fire severity using the equivalent fire severity concept is defined in Ref. 2 (Section 6, Chapter 6). The standard time-temperature curve adopted by the American Society of Testing and Materials (ASTM) is used as an approximation of fire severity in degree hours. Figure 4 shows the standard time-temperature curve as tabulated in NFPA 251 (Ref. 3).

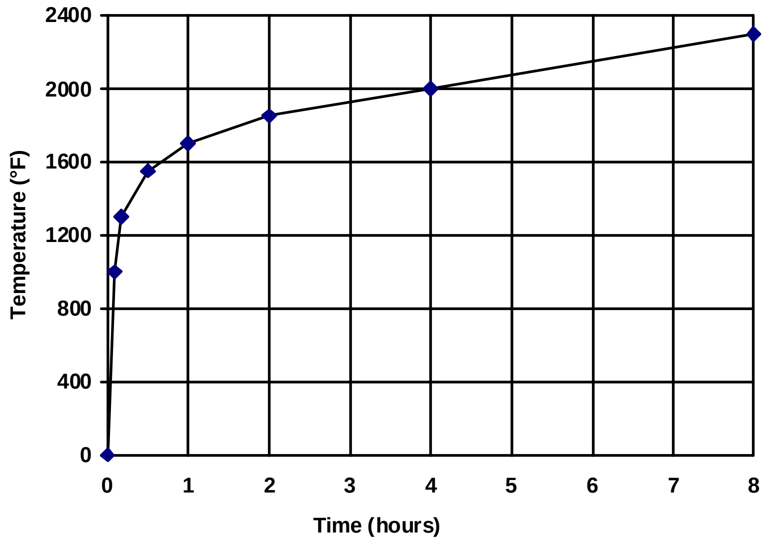

Figure 4—Standard Time-Temperature Curve

Based on the physical condition of the fire location, the size of fire, and the type of detectors, the fire scenario can be modeled to determine the time for the actuation of fire detectors. The response time of heat detectors and fusible-linked sprinklers are calculated using deterministic fire models. These models calculate the activation time of the heat detectors using physical room conditions such as the room temperature, response time index (RTI) for the heat detectors, activation and rate-of-rise temperatures of the heat detectors, room dimensions, detector locations, and fire growth rate.

A more sophisticated fire hazard assessment relies on the development of computational models involving heat transfer, fluid mechanics, and combustion chemistry. These models can estimate the fire growth rate, temperature rise, and smoke generation. The prediction of the fire growth characteristics would require defining the heat release rate, burning rate, radiative and convective heat fluxes, thermal profile of the hot gas layer, and air temperature.

Some fire models predict the occupant decisions and actions during fire using the characteristics of the occupants, status of the occupants, distance from exits, and possible obstructions (e.g., falling structure or dense smoke). These models can account for the fatality and injury rates in such a postulated fire condition. The NFPA Fire Protection Handbook (Ref. 2, Section 10, Chapter 9), surveys the available fire models and describes their applications and special features.

2.3 IMPLEMENTATION OF ASSESSMENT FINDINGS

A successful fire suppression system is considered as one that provides an acceptable probability of success while maintaining a low inadvertent actuation failure rate. A fire hazard analysis identifies the optimal fire protection system for the designed process. The analysis provides the probability and consequence of occurrence of various risks for each system and offers recommendations to minimize or eliminate the fire hazards. The fire protection design criteria are developed after the worst-case fire scenarios are postulated. The fire protection design criteria define the building separation, building layout, walls fire ratings, fire detection types (e.g., thermal detector), fire detection arrangement (e.g., spacing requirement), alarm and notification types (e.g., audible alarm), fire suppression types (e.g., deluge system), fire suppression capacity, fire suppression arrangement (e.g., nozzle spacing density), and sump and draining requirements.

MIL-HDBK-1008B (Ref. 1) outlines the fire protection design criteria for DOD facilities. A fire hazard assessment will confirm that the fire protection design meets the design criteria and assesses the design safety margin in accordance with established fire protection design criteria as outlined in MIL-HDBK-1008. The following areas and equipment are included to confirm compliance with MIL-HDBK-1008B:

- Common Hazards
    1. Heating Equipment
    2. Power Generating and Utilization Equipment
    3. Trash Collection and Disposal
- Special Occupancies and Hazards
- Water Supply for Fire Protection
    4. Water Demand for Sprinklered Area

5. Water Demand for Unsprinklered Area
6. Water Supply Pressure Requirements
7. Quantities of Water Required
8. Sources of Water Supply
9. Fire Pumps
10. Water Distribution System

- Fire Extinguishing Systems

11. Automatic Sprinkler Systems
12. Dry Chemical Extinguishing Systems
13. Portable Fire Extinguishers

- Fire Alarm Systems

14. Fire Alarm Reporting Systems
15. Fire Alarm Evacuation Systems
16. Automatic Fire Detection Systems

A fire hazard assessment is a powerful tool that supports the design effort. The assessment can evaluate the proposed fire protection designs and predict the fire protection system response during a worst possible fire condition. An early fire assessment prevents costly design changes or retrofits after construction.

A fire hazard assessment should be started as soon as the process design criteria are established. The benefit of an early start of a fire hazard assessment is that the early building separations and fire area identifications can minimize fire risks to a defined, controllable level. The fire hazard assessment can define the fire protection design criteria by understanding the fire hazard consequences and their likelihood.

A fire model should be developed to facilitate the analysis of fire protection systems. The model’s sensitivity is measured by fluctuating input parameters such as the fire growth rate, fire detector type and arrangement, combustible loading, and fire suppression mechanism. All computer programs used in performing the fire hazard assessment should be validated and verified before they are implemented in the fire modeling.

3.0 SUMMARY

Because chemical process facilities can involve handling flammable and highly combustible materials, the occurrence of a fire can greatly jeopardize the operating personnel and the facility's safety. A confident fire protection design can only be established after achieving a thorough understanding of the potential for different types of fires. This paper has outlined the fire hazard assessment approach in supporting the fire protection design of a chemical process facility.

To recapitulate, the fire hazard assessment begins with a review of design documents. Based on the design stage, the fire hazard analysis review can range from establishing the basic design criteria to the detailing of P&IDs and PFDs. After the basic design physical barriers are outlined, the fire codes and standards are reviewed to ensure that the fire protection system design complies with applicable fire codes and standards.

The critical fire locations are selected based on the high probability of ignition, fast growth rate, extreme combustible loading, vulnerability of safety-related equipment, potential for loss of life, and significant financial loss. The success of the fire protection system response determines whether the fire loss is acceptable. Among the acceptable and unacceptable fire losses, the most credible fire losses will be analyzed to determine the severity of both an acceptable and an unacceptable fire loss.

The traditional fire hazard assessment uses the equivalent fire severity by comparing the total heat of combustion of a given fuel package with a known constant. The fire severity is measured by the standard time-temperature curve in degree hours. However, this traditional approach in fire safety assessment is not adequate in determining a specific fire scenario in a chemical process facility, which may be beyond the expected fire magnitude level.

With the advent of powerful computer hardware and software, analyses can now be performed that were considered beyond our technological capability just a few years ago. Many computer models are available that can determine the result of a postulated fire based on the detail and accuracy of the input model. These fire models can determine the fire detector response time and the size of the fire when the fire suppression system is activated. The fire severity models can determine the structure response and, based on the characteristics of the occupants, the models can be used to evaluate the survival rate.

A fire hazard assessment results in a series of recommendations that will address the adequacy of the response time and the suppression capability. The recommendations result in establishing fire protection design criteria and modifications to improve the safety of the personnel and the facility during a fire.

4.0 REFERENCES

1. MIL-HDBK-1008B, Fire Protection for Facilities Engineering, Design and Construction, 1994.

2. NFPA Fire Protection Handbook, 17th Edition, 1991.

3. NFPA 251, Fire Tests of Building Constructions and Materials, 1995.